FINAL REPORT ON IMPROVED SEA KING 3D MODELLING FOR THE 3D DATA ACQUISITION AND MODELLING SERVICES PROJECT

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On behalf of
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Contractor Report

DRDC Toronto CR 2003-091

2003-07-23

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Author: _____ _____
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Project Manager: _____ _____
Rajesh Jha Date

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Abstract

An improved 3D graphics model of the interior and exterior of a SeaKing Helicopter has been developed for simulation and modelling purposes. An existing polygon graphics model was modified to include some missing features, improve certain features, and to add range of motion objects for pedals, sticks, and seats. The interior model was surfaced conventionally using NURBS objects to improve storage and operating efficiency. The polygon model was created using Innovmetric Polyworks software and the NURBS using the Rhino modelling package. Models were built from laser scan data measured by Cyrax and Shape Grabber laser scanners, and consist of polygon and/or NURBS surfaces of the interior and exterior of the SeaKing. They incorporate range of motion objects for the seats, pedals, control sticks. They also include schematic representations of the position of major panel and console dials, indicators and controls. A validation of the final models compared to the original scan data indicates a mean error of less than 3 mm.

Résumé

Un modèle graphique 3D amélioré de l'intérieur et de l'extérieur d'un hélicoptère Sea King a été élaboré pour répondre aux besoins en simulation et en modélisation. Un modèle graphique en polygones existant a été modifié afin d'inclure quelques caractéristiques manquantes, d'améliorer certaines caractéristiques et d'ajouter la plage de déplacement des objets pour les pédales, les manches et les sièges. On a surfacé le modèle de l'intérieur de manière classique par la technique des objets NURBS afin d'améliorer le stockage et l'efficacité opérationnelle. Le modèle en polygones a été créé au moyen du logiciel Innovmetric Polyworks et de la technique des objets NURBS à l'aide du groupe de modélisation Rhino. Les modèles ont été construits à partir de données de balayage au laser obtenes à l'aide de scanners au laser Cyrax et Shape Grabber, et ils sont constitués de polygones et (ou) de surfaces NURBS de l'intérieur et de l'extérieur d'un Sea King. Les modèles comprennent la plage de déplacement des objets pour les sièges, les pédales et les manches de commande. Ils comprennent également des représentations schématiques de la position des principaux cadrans de panneaux et de pylônes de commande, des indicateurs et des commandes. Une validation des modèles finaux par rapport aux données de balayage originales indique une erreur moyenne inférieure à 3 mm.

Executive Summary

This report summarizes the work and results of the call-up 7752-02. The purpose of this call-up was to check, modify, and improve a 3D graphical model of a CF Sea King helicopter.

In addition to an existing polygon model of the exterior and interior of the Sea King, scan data and digital images of two Sea Kings were provided. Most of the laser scanning was performed using a Cyrax laser scanner, with some interior scanning using a ShapeGrabber laser scanner. The nominal accuracy of the Cyrax laser scanner is approximately 6 mm, while the nominal accuracy of the ShapeGrabber scanner is approximately 0.5 mm.

The following tasks were completed:

1. Window straps on the front windshield of the Sea King were added to the model.

2. The locations of dials, gauges and controls were added to the front control panel and to the center consoles.

3. The head of a cyclic and collective were rescanned and added to the model to improve their representation.

4. The pilot's "parking-brake" attachments above the main pedals were added to the model.

5. Range of motion objects for the pedals, sticks, and seats were added to the model.

6. The relative location of the front control panel with respect to the front window frame was improved, resulting in a movement of 15 cm compared to its initial position.

7. The shape and construction of the graphics model of the front panel glare was improved.

8. Approach plates, located on each side of the front panel, were added to the model.

9. Two missing lower front windows were added to the model.

10. The interior of the cockpit was remodeled using conventional surfacing in Rhino with NURBS objects.

A validation of the final models compared to the original scan data indicates a mean error of less than 3 mm.

Sommaire

Le présent rapport résume le travail qui a été accompli à la suite de la demande de propositions 7752-02. Cette demande de propositions avait pour objet la vérification, la modification et l'amélioration d'un modèle graphique 3D d'un hélicoptère Sea King des FC.

En plus d'un modèle en polygones existant de l'extérieur et de l'intérieur d'un Sea King, on a fourni des données de balayage et des images numériques de deux Sea King. La plus grande partie du balayage laser a été effectuée à l'aide d'un scanner au laser Cyrax, et une partie du balayage intérieur a été faite à l'aide d'un scanner au laser ShapeGrabber. La précision nominale du scanner au laser Cyrax est d'environ 6 mm, tandis celle du scanner au laser ShapeGrabber est d'environ 0,5 mm.

Les tâches suivantes ont été exécutées :

1. on a ajouté des rubans de fenêtre au pare-brise avant du modèle du Sea King;

2. on a ajouté les emplacements des cadrans, des jauges et des commandes au panneau de commande avant et aux pylônes de commande centraux;

3. on a balayé de nouveau la tête d'un manche de pas cyclique et d'une poignée de levier de collectif et on a ajouté ces éléments au modèle afin d'améliorer leur représentation;

4. on a ajouté au modèle les fixations du « frein de parc » du pilote au-dessus du palonnier principal;

5. on a ajouté au modèle la plage de déplacement des objets pour les pédales, les manches et les sièges;

6. on a amélioré la position relative du panneau de commande avant par rapport au cadre de la fenêtre avant, ce qui a résulté en un déplacement de 15 cm par rapport à sa position initiale;

7. on a amélioré la forme et la construction du modèle graphique de l'écran antireflet du panneau avant;

8. on a ajouté au modèle les feuilles de percée situées de part et d'autre du panneau avant;

9. on a ajouté au modèle les deux fenêtres avant inférieures manquantes;

10. on a remodelé l'intérieur du poste de pilotage à l'aide d'un dispositif de surfaçage classique en Rhino avec la technique des objets NURBS (B-spline rationnelle non uniforme).

Une validation des modèles finaux par rapport aux données de balayage originales indique une erreur moyenne inférieure à 3 mm.

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1 INTRODUCTION AND BACKGROUND SUMMARY

[1] Operations on the second call-up tasks of Array's standing offer began on March 10, 2003. The overall purpose of this call-up was to check, modify, and improve a 3D graphical model of a CF Sea King helicopter.

[2] In addition to an existing polygon model of the exterior and interior of the Sea King, scan data and digital images of two Sea Kings were provided. Most of the laser scanning was performed using a Cyrax laser scanner, with some interior scanning using a ShapeGrabber laser scanner. The nominal accuracy of the Cyrax laser scanner is approximately 6mm, while the nominal accuracy of the ShapeGrabber scanner is approximately 0.5mm.

[3] Several areas of concern regarding the existing 3D graphical model were identified and discussed during meetings at the start of the call-up. These were modified throughout the call-up, in frequent conversations while the consultant was working on site at DRDC Toronto.

[4] The initial concerns consisted of the following:

1. Window straps on the front windshield of the Sea King are missing. These are used by the pilots for navigation purposes, and should be added to the model.
2. The models of the control panels were oversimplified, the locations of dials, gauges and controls was desired for various purposes.
3. The cyclic and collective control sticks are oversimplified, and lack realistic detail for simulations.
4. The pilot's pedals are missing some detail, specifically a "parking-brake" attachment above the main pedals.
5. Range of motion indicators for pedals, sticks, and seats are not part of the existing model, and are necessary for the desired reach studies.

[5] Aside from the window straps, the majority of concerns are related to the interior of the helicopter cockpit. As the original scans of this area were lacking sufficient coverage to address the above items, additional scan data of a second Sea King was provided by DRDC. This Cyrax data included range-of-motion data for the above noted items.

[6] Early on in the call-up, once the investigation began, additional problems with the existing model were discovered. These include:

1. The location of the front control panel with respect to the front window frames was found to be inconsistent between the existing model and the scan data on the second Sea King. This discrepancy is up to 15 cm, and is illustrated in Figure 1.

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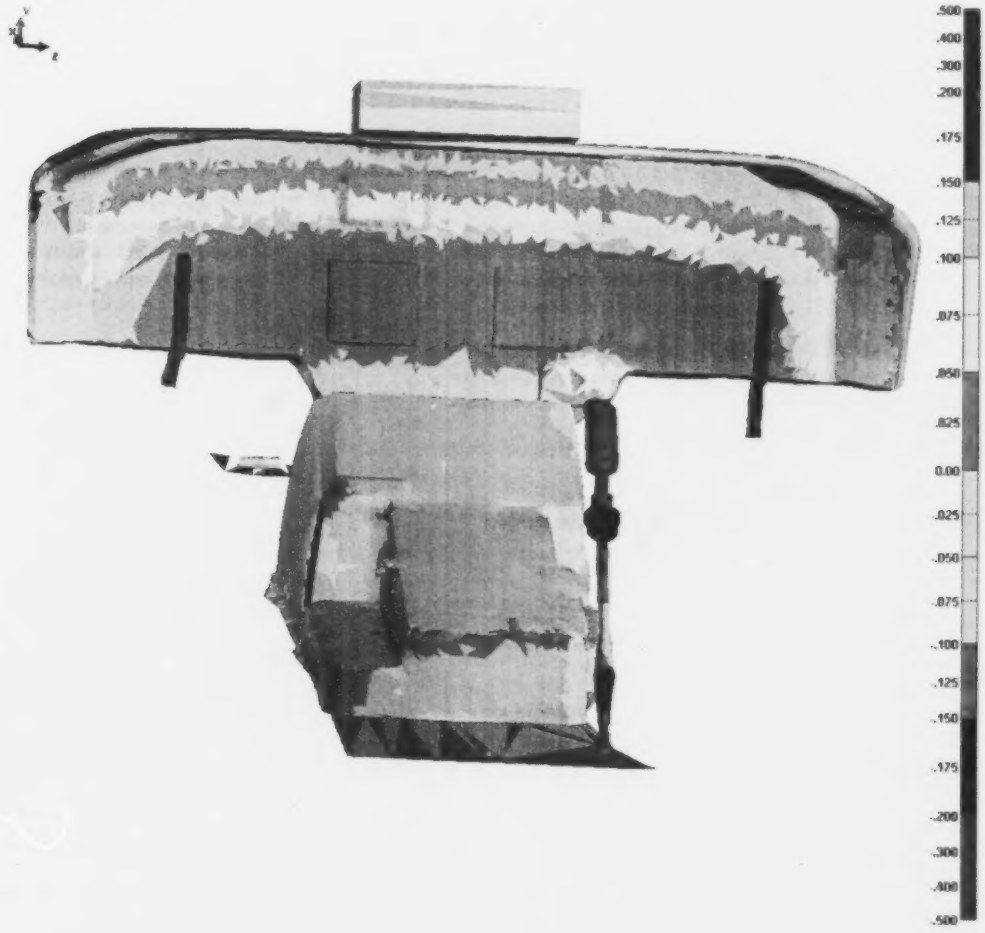

Figure 1. Discrepancy in Panel/Console Position

2. The shape and construction of the graphics model of the front panel glare shield did not conform to the digital images, as shown in Figure 2 and Figure 3.

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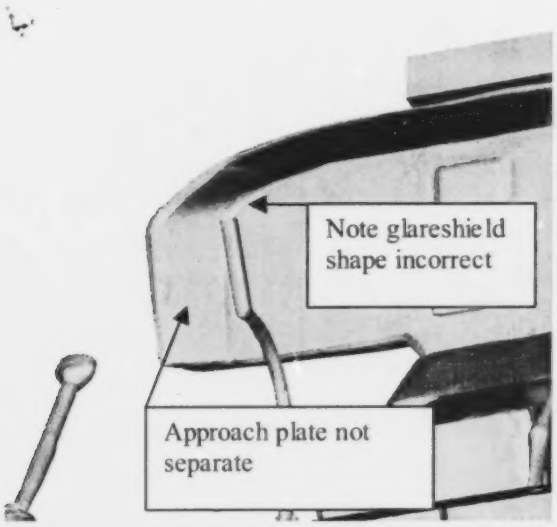

Figure 2. Existing Panel Model

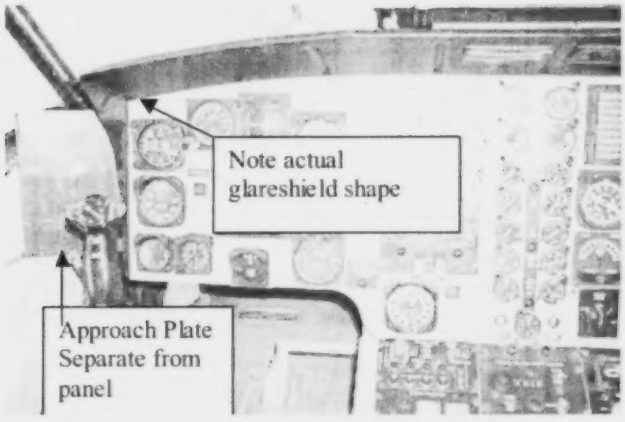

Figure 3. Digital Image of Sea King Front Panel

3. Approach plates, located on each side of the front panel, were incorrectly attached and merged with the front panel, again, as shown in Figure 2 and Figure 3.
4. Two lower front windows were missing from the existing model.
5. Insufficient scan data was available to model the tops of the control sticks.

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[7] As a result of these items, and those above, it was decided to completely remodel the interior of the cockpit.

[8] The following practices and methods were adopted in the 3D modelling:

1. The exterior of the existing model was used as a basis for alignment of the interior. This model was modified by adding the missing straps and windows, otherwise it would remain as-is. Thus, the data source for most of the exterior data remains the 1st scanned Sea King.

2. The interior of the cockpit was remodelled primarily using Cyrax data collected on the 2nd Sea King. The exception is the location of the panel details (knobs, dials, etc.), which is based on ShapeGrabber data from the original Sea King.

3. Innovmetric's Polyworks software suite was used to convert and align individual scans, polygonize data, and align relative components to each other (e.g. seats, panel, sticks, etc.). It was also used for polygon model tolerance reduction, and final inspection with respect to scan data.

4. Conventional surfacing using Rhino was chosen for interior re-modelling of the cockpit. This surfacing used NURBS surfaces now available in a native IGS format, as well as polygonized formats such as stl and dxf.

5. Components in the cockpit model are logical entities, grouped across layers according to functions and/or positions. This provides maximum flexibility in the data applications, as individual items, groups, etc. can be exported, polygonized, and/or converted to a variety of formats. Also, it is easy to add (attach or detach items), or modify objects as needed.

6. Due to the large amount of data from the scanning, individual component assemblies (pedals, seats, etc.) were aligned in Imalign, separately polygonized and tolerance reduced using Immerge, and assembled globally using Iminspect.

7. Polygon tolerance reduction in general used a threshold of 0.5mm.

8. The data is to be delivered in formats requested by DRDC for its current tasks, including both the Rhino and Polyworks models of the data. The improved cockpit is added into the existing model to replace the existing interior cockpit.

9. The existing coordinate system of the old model is maintained, with new scans transformed to this reference system. This maintains consistency with the any existing legacy applications of the model.

10. Settings used for polygon merging are as follows for Cyrax scan data:

    Spatial Neighborhood: 10X sampling, Typ. 0.02 m
    Sampling: as per scan interpolation, usually 0.002 m
    Tolerance: 0.0005 m
    Smoothing radius: Typ 0.005 m (based on 2.5X sample step)
    Smoothing tolerance: Typ. 0.005 m (based on 3X Imalign std.dev)

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2 INDIVIDUAL TASK REPORTS AND NOTES

2.1 Missing Window Straps Added to Model

[1] Scan data from the second Sea King was used as a data source for the straps. Three-dimensional polyline curves were fit to the strap edges to provide smooth transitions, which were then inserted into the original model. The results are shown in Figure 4. The task involved modifying the exterior shell, interior shell, and interior and exterior windows. Software used is Innovmetric's Imalign, Immerge and Imedit.

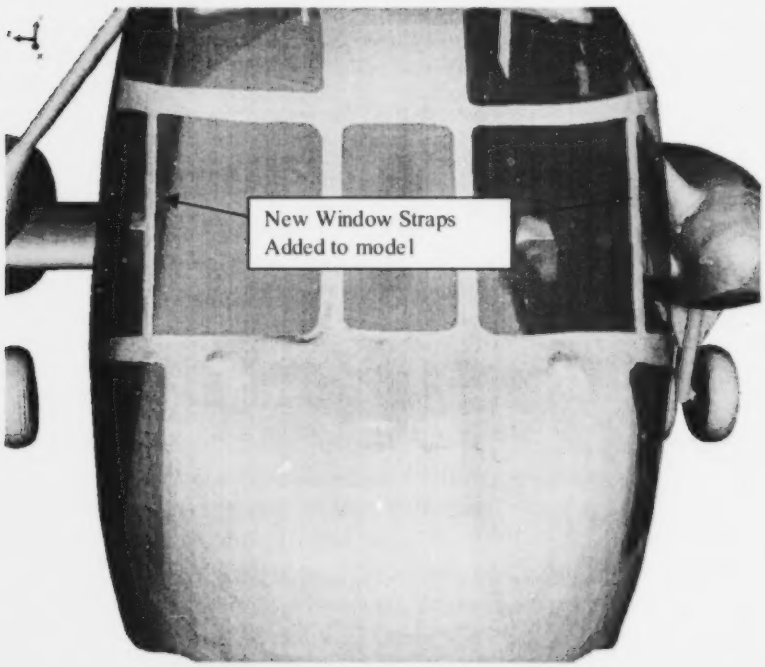

Figure 4. Window Straps Detail

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2.2 Missing Lower Windows Added to Model

[1] Scan data from the second Sea King was again used as a data source. Three-dimensional polyline curves were fit to the window perimeters to provide smooth edges, which were inserted/sliced into the original model. The results are shown in Figure 5. The task involved modifying the exterior shell, interior shell, and interior and exterior windows for completeness. The new windows were also added to the existing window material groups. The new windows are also inserted into the polygon mesh, resulting in a clean continuous model (no gaps). Software used is Innovmetric Imalign, Immerge and Imedit.

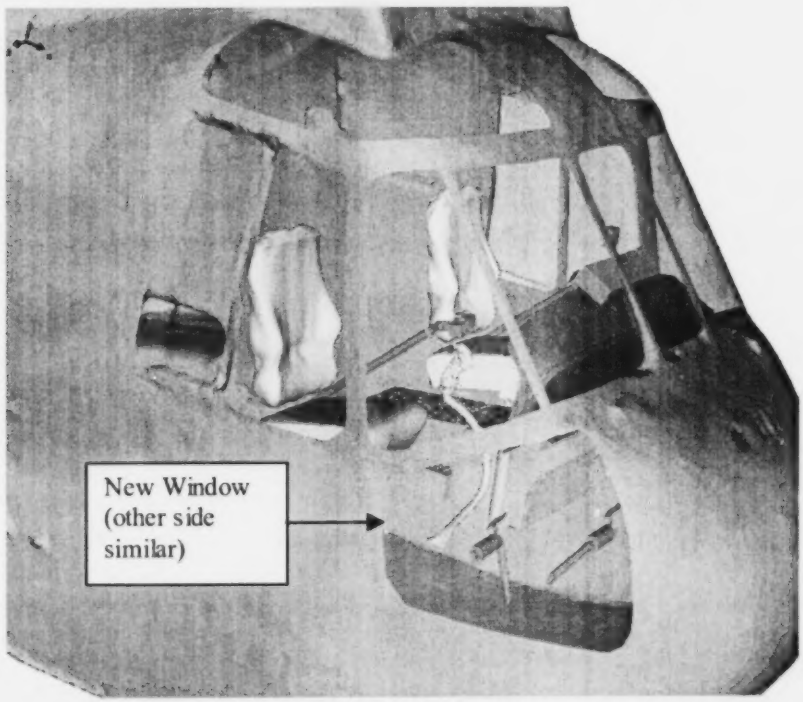

Figure 5. New Cockpit Windows

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2.3 Remodel Front Panel and Center Consoles

[1] The front panel and center consoles were remodelled using both Cyrax scan data from the second Sea King (for panel shape and location), and ShapeGrabber scan data for the panel details (dials, knobs, etc.).

[2] The original and new assemblies are shown in Figure 6 and Figure 7, with significant changes noted below.

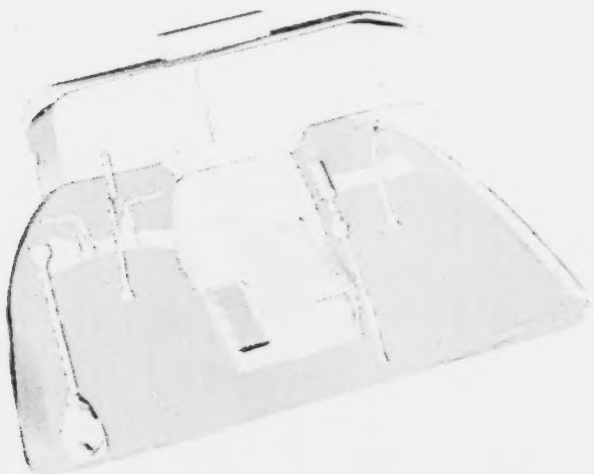

Figure 6. Existing Panel/Console

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Figure 7. Remodelled Panel/Console

2.3.1 Glare Shield and Approach Plates

[1] As mentioned in the Introduction, these were improperly represented in the original model, evident by comparing Figure 2 and Figure 3.

[2] The new panel model, with an improved glare shield and new approach panels was conventionally surfaced in Rhino, using cross-sections and primitive geometrical objects exported from Iminspect, with locations determined from the polygonized scan data.

2.3.2 Adjusted Front Panel and Center Console Positions

[1] In addition to the concerns regarding the existing panel's shape and construction, a significant discrepancy in its spatial location was also discovered. It is believed that the discrepancy was the result of the original scanning approach to join the interior and exterior scans. In the original scan, windows were covered, and through-the-window scan data of the front panel was not taken. Instead, it appears the position was taken from through-cargo-door scans, connecting interior and exterior. As the door is quite far from the front panel, an accumulation of alignment and geometry errors likely resulted. As the alignment groups for this data could not be located, it is impossible to investigate further, and or correct the position using original scan data.

[2] An alternate approach was taken, by using the scan data from the second Sea King to locate the new panel assembly. Figure 8 visually illustrates the discrepancy of the old and new panel locations, corresponding to the previous Figure 1 which is a colour map indicating the actual difference across the panel.

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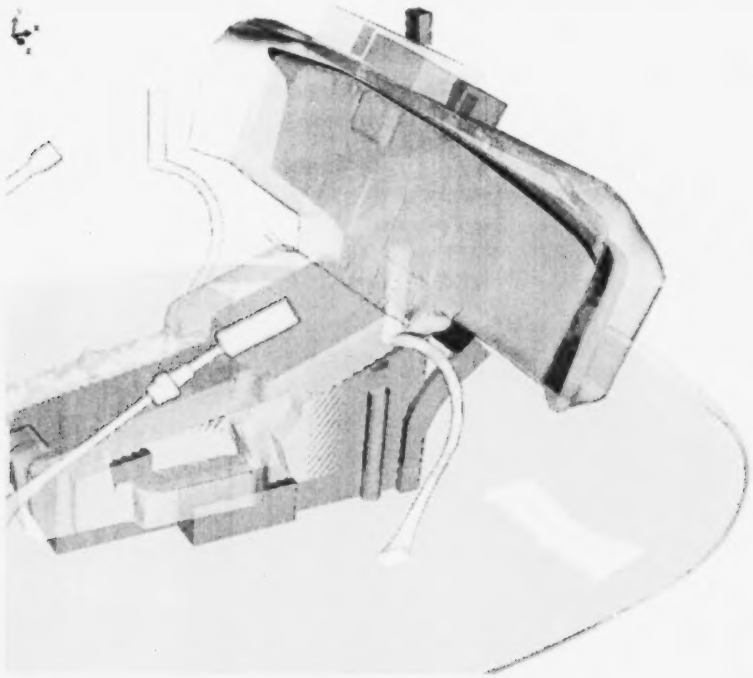

Figure 8. Location of Existing and New Panel Models

[3] In addition, the floor location was also different by several centimeters, and was also remodelled according to the Cyrax scan data.

[4] The panels and floor were positioned with respect to the exterior shell, particularly the existing window frame edges. It is unlikely that these features differ significantly among Sea Kings, as replacement windows would not fit properly if that were the case.

[5] The panel, consoles, and floor were modelled conventionally in Rhino, positioned according to data exported from Iminspect, based on the realigned and polygonized Cyrax scan data of the second Sea King. As parts of the panel (different edges) were captured from different Cyrax scans, there is some redundant location landmarks of the panel. The separate scans were combined, and aligned to the global coordinate system using Iminspect.

2.3.3 Add Panel Details

[1] As part of this call-up, the locations of instrumentation and controls on the front panel and center consoles were added to the model. These included gauges, dials, knobs, levers, switches, indicator lights, etc. It was noted that these were not in the original model. Generally, the items were conventionally surfaced as circles, rectangles, cylinders, and lines. The results are shown in Figure 9. Their locations were based on digitizing points from the polgonized shape grabber data, as aligned in both Imalign (for the local scans) and Iminspect (polygon model aligned to the global coordinate system).

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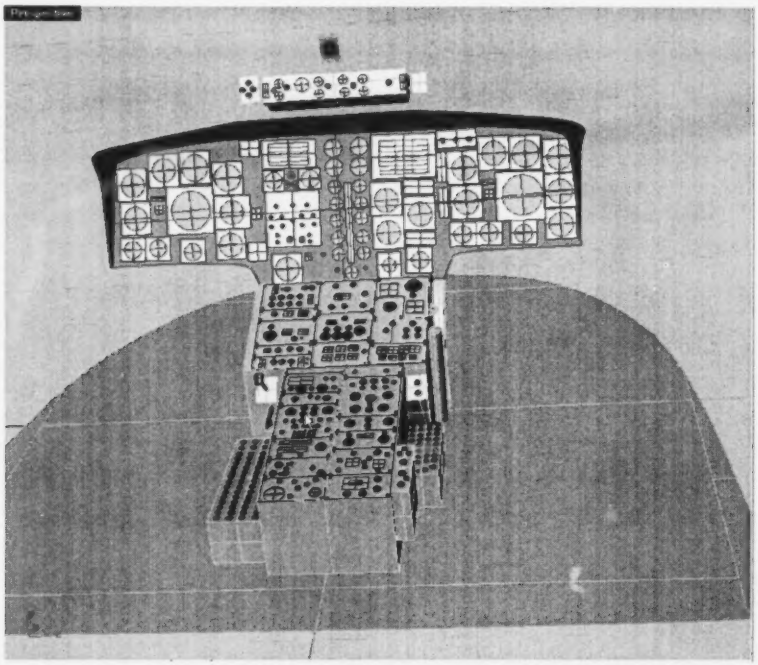

Figure 9. Console and Panel Details

[2] As Shape Grabber scan coverage of the entire panel was incomplete, the location of some details was derived from digital images, such as Figure 10. It appears from the digital images, and confirmed from some of the partial panel scan data, that the relative positions of some clusters of pilot and copilot gauges are identical. This observation was used to facilitate detail panel modelling for the pilot gauges, as the scan data was also incomplete. As the original model did not contain control handles on the sides of the consoles, including the landing gear control handle, and scan data was not available for these handles, they were added to the model using the partial scan information available, and details from the digital images. As a result, the positions and/or shape of these handles may be inaccurate compared to other items on the control panels.

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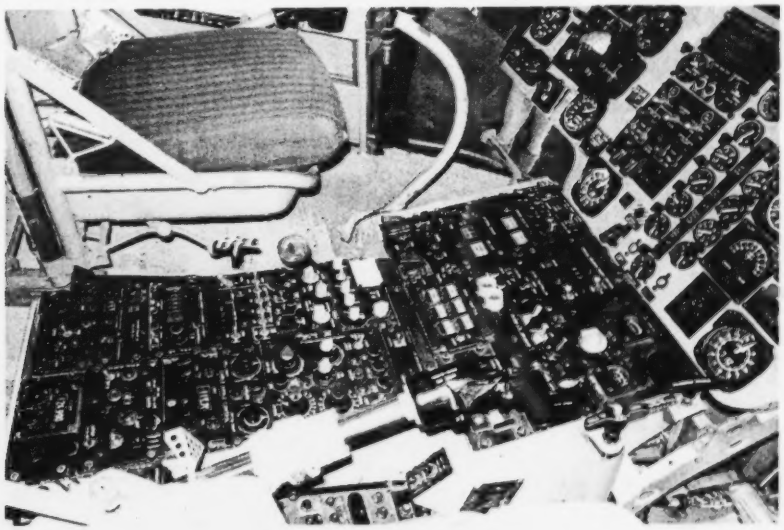

Figure 10. Front Panel/Console Details

[3] From the digital images, such as Figure 11, it is also noted that certain smaller control panels, located on the seat hand rests, or on the door frames were not modelled in the original model. Also, scan data couldn't be located for any of these panels. As a result, they could not be modelled in the new model. If they are to be later added to the model, alternatives are to remodel them using only photographs, plans, or by taking additional cockpit scan data.

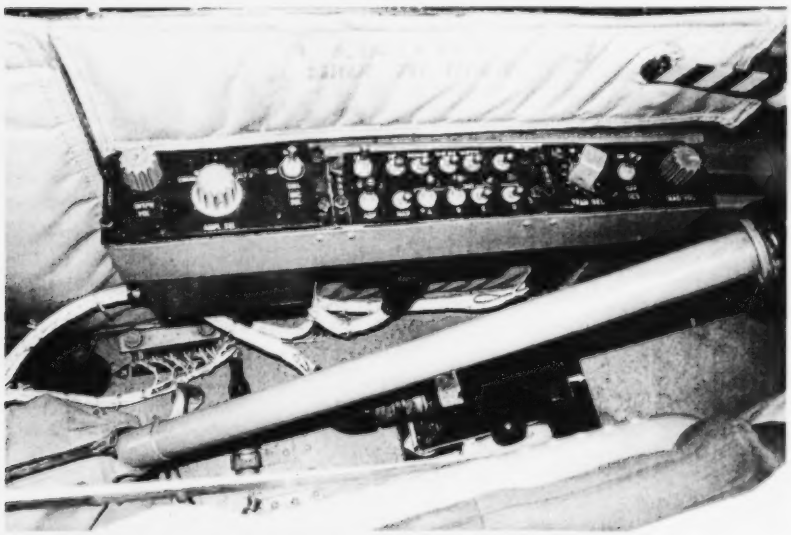

Figure 11. Example of Additional Controls Not Currently In Model

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[4] Also, for the overhead control panels, shown in Figure 12, although their rough shape outline is modelled in the original model, scan data for these panels could not be located. In particular, the details of the panel do not appear to have been scanned, as the front and center panels were with the Shape Grabber. For this reason, the overhead panels were also not revised in the new model, but instead their legacy representation is carried forward to the new model.

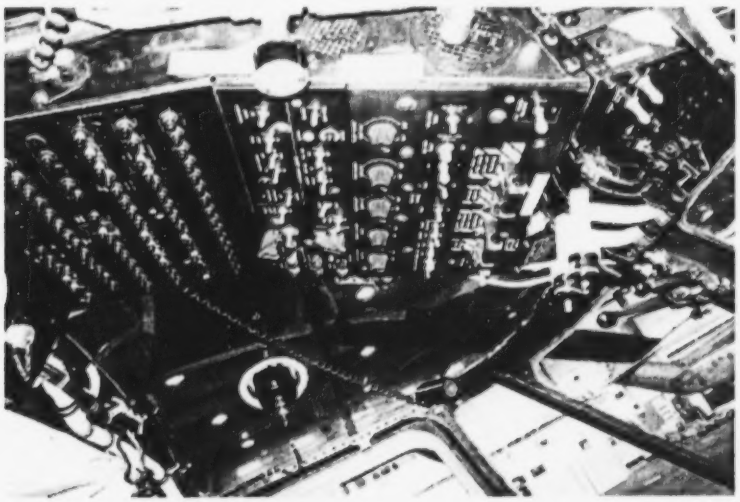

Figure 12. Overhead Control Console

2.4 Remodel Pedals and Add Range of Motion (ROM)

[1] As mentioned in the Introduction, DRDC expressed two issues related to control pedals. First, range of motion positions of the pedals were not modelled. Second, the upper attachment to the pilot's pedals was missing in the model. The pedals were surfaced conventionally in Rhino using Cyrax scan data from the second Sea King. This data also provided range of motion. It was noted that the pedals can be physically translated to two positions, forward and aft, and also rotated to two deflections (max right foot forward, max left foot forward). Scan data sufficient to locate the pedals in these positions was located.

[2] Rhino was used for surfacing, based on alignment and position locations derived in Imalign (individual scan groups) and Iminspect (global alignment of pedal assembly in helicopter coordinate system.

2.4.1 Pilot Side

[1] The Pilot's side pedals were remodelled, including the addition of the top portion (parking brake) as shown in Figure 13, and the digital image shown in Figure 14.

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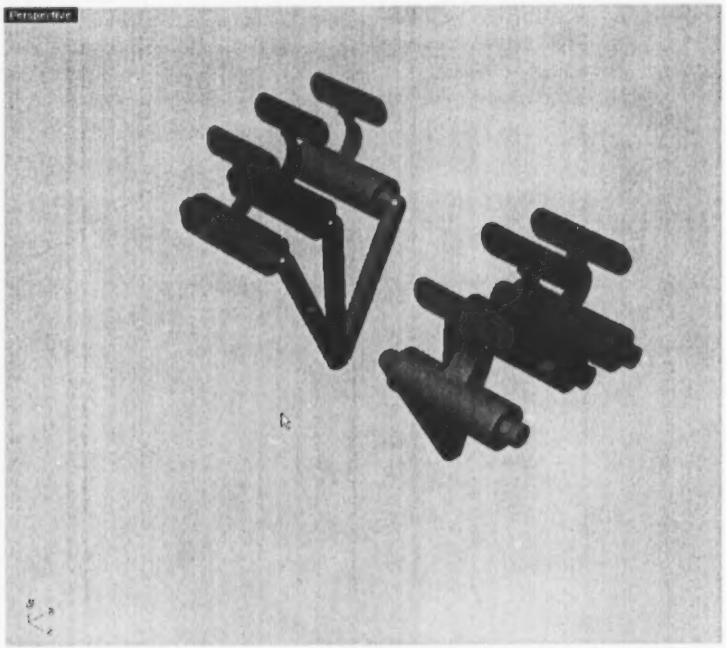

Figure 13. Pilot Side New Pedal Model and ROM

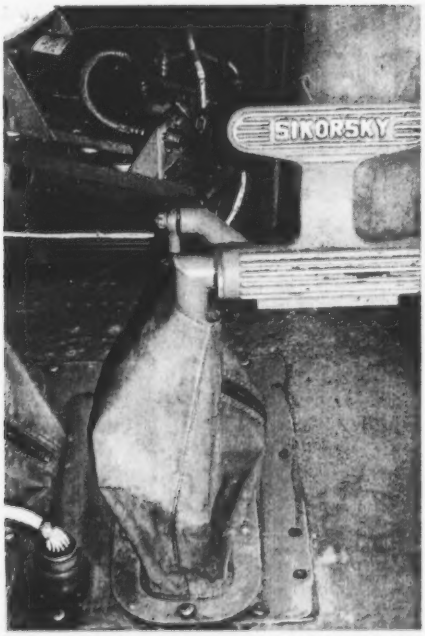

Figure 14. Pilot Pedal Assembly Digital Image

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[2] The range of motions were added in Rhino, and the resulting NURBS surfaces are shown in Figure 13.

2.4.2 Co-Pilot's Side

[1] The co-pilot's side pedals were also surfaced conventionally in Rhino, similar to the Pilot's, with the exception that these pedals do not have the top attachment. The scan data is again from the Cyrax scans on the second Sea King.

[2] The final models and ranges of motions are shown in Figure 15.

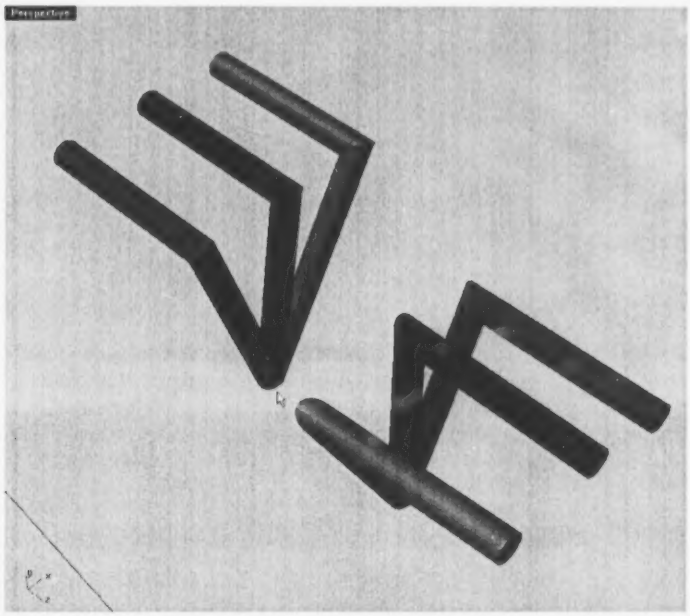

Figure 15. Co-Pilot Pedal Model and Range of Motion

2.5 Remodel Cyclics and Add ROM

[1] There were two areas of concern noted regarding the Cyclics. First, Range of Motion (ROM) was not indicated in the model. Second, the cyclic heads were represented as cylinders, shown in Figure 16 in comparison with their actual complex shape, shown in the digital image in Figure 17.

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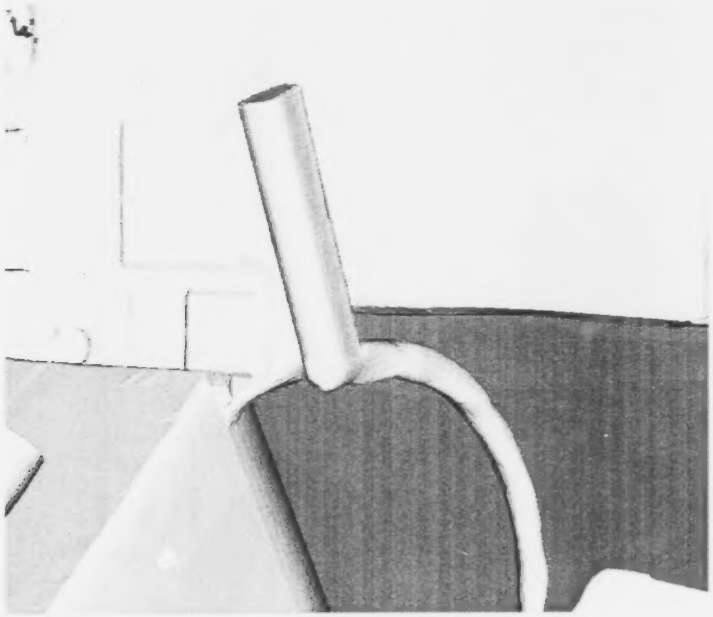

Figure 16. Existing Cyclic Head Model

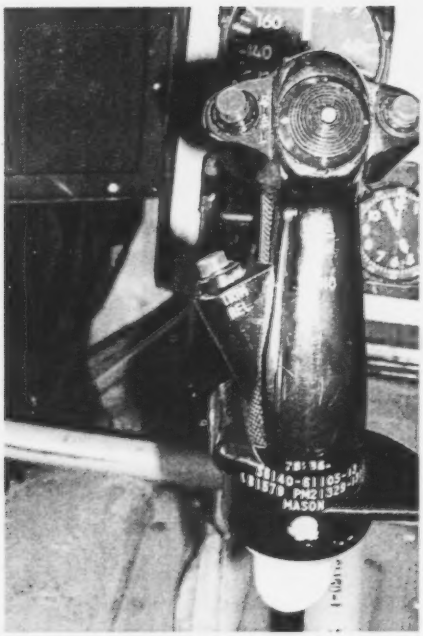

Figure 17. Actual Cyclic Head Digital Image

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[2] Since sufficient scan data to model the cyclic head could not be located, it was decided to obtain a cyclic and collective from a helicopter and scan it in the DRDC laboratory using the ShapeGrabber. Since the shape of the cyclic is quite complicated, it was decided not to conventionally surface it, but to use polygon mesh objects to represent it.

[3] At DRDC, Canadian Forces (CF) cyclic and collective parts were not available, however, similar US models were available for scanning. For the cyclic, it appears from digital images that the shape of the US and Canadian models are identical. Figure 18 shows the cyclic head scanned for this study. Note that because they are shiny black objects, ShapeGrabber experienced problems scanning the objects due to well known surface effects.

[4] To counteract these effects, we applied white tape over the objects to provide sufficient shape definition. Note however, that there is some loss of detail with this approach. If this detail is needed in the future, the sticks may be magnafluxed (covered with a chalk powder) and rescanned.

Figure 18. US Model Cyclic Head Scanned for Model

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[5] The scans were aligned in Imalign, polygonized, and Imedit was used to smooth and enhance the polygon model. Some holes were filled, but larger ones still remain due to time limitations.

[6] Once a suitable polygon model was created for the cyclic, using the cyclic head data, and the existing cyclic stick model, range of motions were added based on fitting the object to Cyrax scan data from the second Sea King.

[7] Note that the following geometrical condition was imposed on the range of motion: the pilot's and co-pilot's cyclics were modelled as being linked, in that the translations, range of motion, and direction vectors of each (in all degrees of freedom) are consistent for each position of pilot and copilot cyclic. For example, in upper left position, both cyclics have the same spatial orientation. It is also assumed that all ROM positions for each have common origins, one for the pilot's cyclics, one for the co-pilot's. These assumptions were verified using scan data and internal DRDC information.

[8] It is noted that the cyclic origins do not lie on the cockpit floor surface, but rather underneath it, based on fitting the objects to the scan data. It is assumed that both the pilot and co-pilot cyclics have the same shape and size. This was however, not directly verified. The resulting cyclics and ROM are shown in Figure 19. The cyclics were scanned (and are thus modelled) in extreme positions, upper left, right, lower left right, left extreme, right extreme, upper and lower center extremes, and also neutral position.

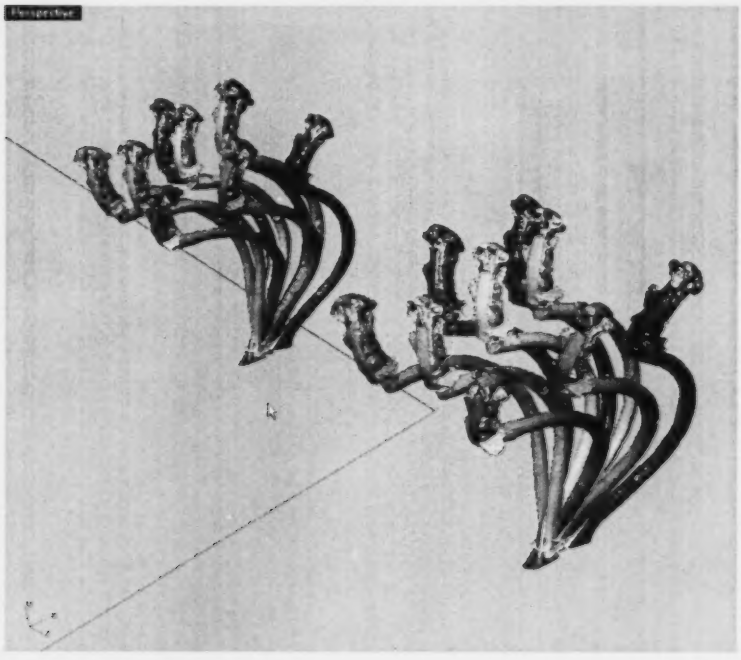

Figure 19. New Cyclic Models and ROM

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[9] An important discovery related to the cyclic range of motion is that it collides with and is interfered by the seat cushion when in lower extreme positions, with the seat at its uppermost and forward most positions. This is further illustrated in the section below on the seat models.

2.6 Remodel Collectives and add ROM

[1] There were two areas of concern noted regarding the Collectives. First, Range of Motion (ROM) was not indicated in the model. Second, the collective heads were overly simplified, shown in Figure 20 in comparison with their actual complex shape, shown in the digital image in Figure 21.

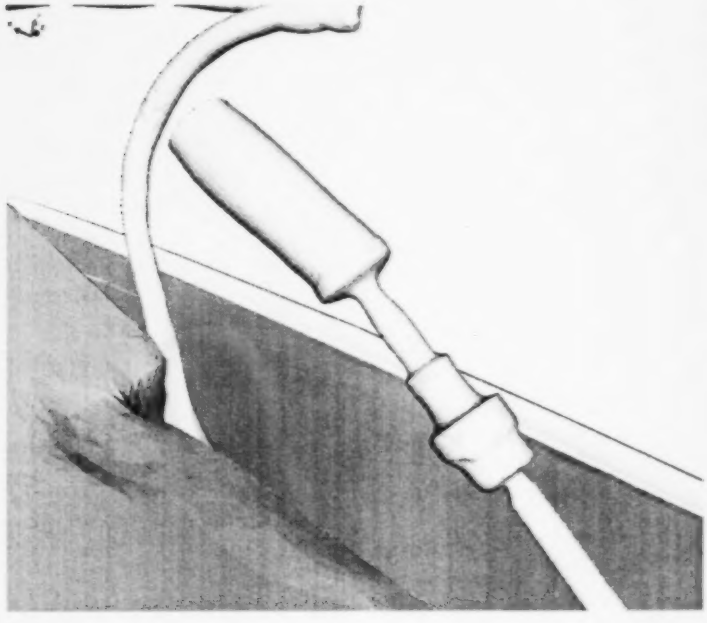

Figure 20. Existing Collective Model

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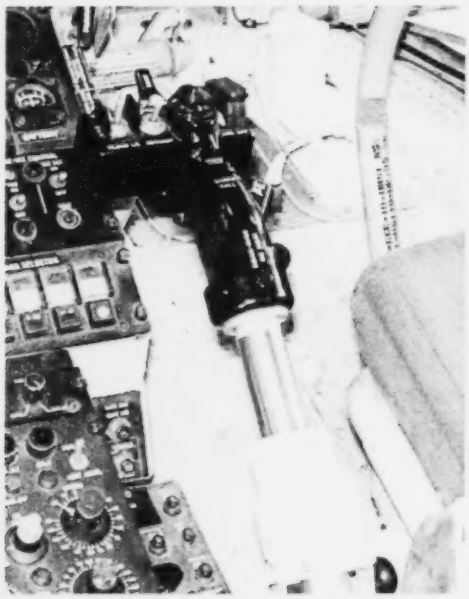

Figure 21. Actual Collective Head Digital Image

[2] Since sufficient scan data to model the collective heads could not be located, it was decided to obtain a collective (as with cyclic above) from a helicopter and scan it in the DRDC laboratory using the ShapeGrabber. Since the shape of the cyclic is fairly regular, it was decided to conventionally surface it in Rhino, unlike the polygon mesh object used to represent the cyclics.

[3] At DRDC, CF cyclic and collective parts were not available, however, similar US models were available for scanning. Unlike the cyclics, for the collective, it appears from digital images that the shape of the US and Canadian models are different.

[4] Figure 22 shows the collective head scanned for this study, and Figure 21 shows the actual Canadian Sea King collective head. Note that because they are shiny black objects, ShapeGrabber experienced problems scanning the objects due to the well known surface effects.

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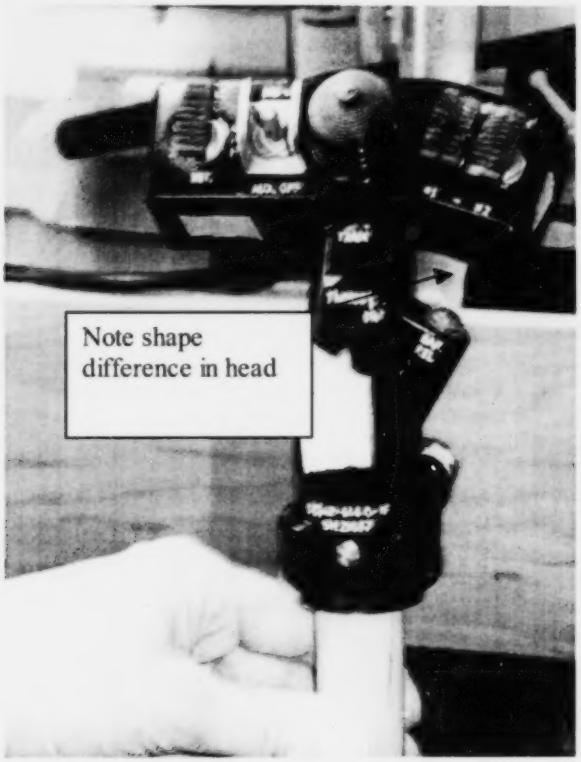

Figure 22. US Model Collective Head (note shape difference)

[5] To offset this effect, we again applied white tape over the objects to provide sufficient shape definition. Note again there is some loss of detail. If this detail is needed in the future, the sticks should be magnafluxed (covered with a chalk powder) and rescanned.

[6] Once suitable Rhino objects were created for the collectives, using the new collective head and stick data, range of motions were again added based on fitting the object to Cyrax scan data from the second Sea King.

[7] Note that the following geometrical conditions were imposed on the range of motion: the pilot's and co-pilot's collectives were modelled as though physically linked, in that the translations, range of motion, and direction vectors of each (all degrees of freedom) are identical for each position of pilot and co-pilot collective. It is also again assumed that all ROM positions for each have common origins, one for the pilot's collective, and one for the co-pilot's. These assumptions were verified using scan data and internal DRDC information.

[8] It is noted that the collective origins do not lie on the cockpit floor surface, but rather underneath it, based on fitting the objects to the scan data.

[9] It is further assumed that both the pilot and co-pilot collectives have the same shape and size. This was not directly verified.

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[10] The resulting collectives and ROM are shown in Figure 23. The collectives (like cyclics) were scanned (and are thus modelled) in extreme positions forward and aft (or up and down).

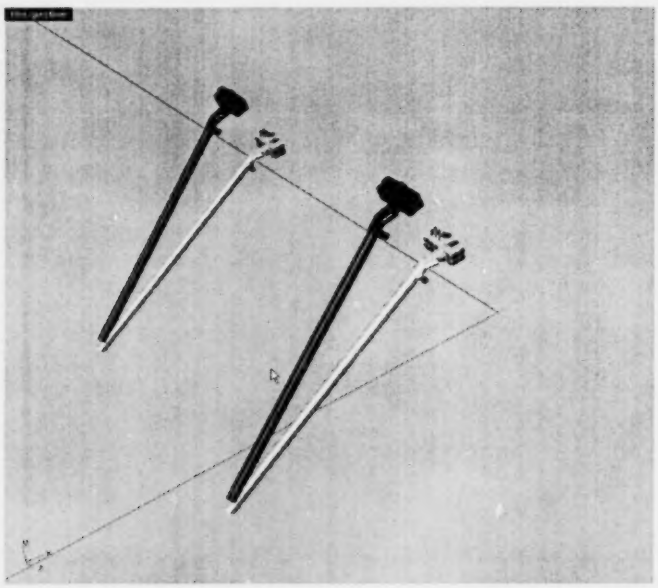

Figure 23. Collective Models and ROM from Rhino

2.7 Remodel Seats and Add ROM

2.7.1 General Notes on Seat Modelling

[1] The seat modelling represented one of the most time consuming and challenging parts of this project for the following reasons.

1. Limited scan data was available, and this data was often obscured by other objects.
2. Each seat was aligned with six degrees of freedom (three translations and three rotations).
3. Seats were removed in the first Sea King for scanning, but left in place in the second Sea King.
4. Seat cushions were complicated and not rigid, as they had some wrinkles in the back-rest.

[2] Initially, to save time, the existing seat model was improved using Imedit and used in the new model, with range of motions added. However, it became evident from the attempted alignment of the seats in the cockpit, that this model was insufficient. The main problem is the apparent misalignment in the model of the seat rest to seat cushion as compared to the available scan data from the second Sea King.

[3] As a result, and also to improve the model's efficiency and reduce polygon count, a NURBS model in Rhino was created of the seat cushions, while still using the existing seat back frame

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only for part of the seat alignment. Fine vertical seat alignment used the new Rhino seat cushion model. As a result, the seat frame is modelled using polygons from the old model (with some clean up editing and polygon tolerance reduction), while the seat cushions themselves are modelled using Rhino NURBS.

[4] Figure 24 shows the seat back and frame model (polygons) while Figure 25 shows the NURBS seat cushion models (Rhino). It is recommended in the future to use only the seat cushion model for any further studies and simulations, although both seat model representations are provided. The alignment of the cushions is considered more accurate and realistic than the seat frames, based on the verification below.

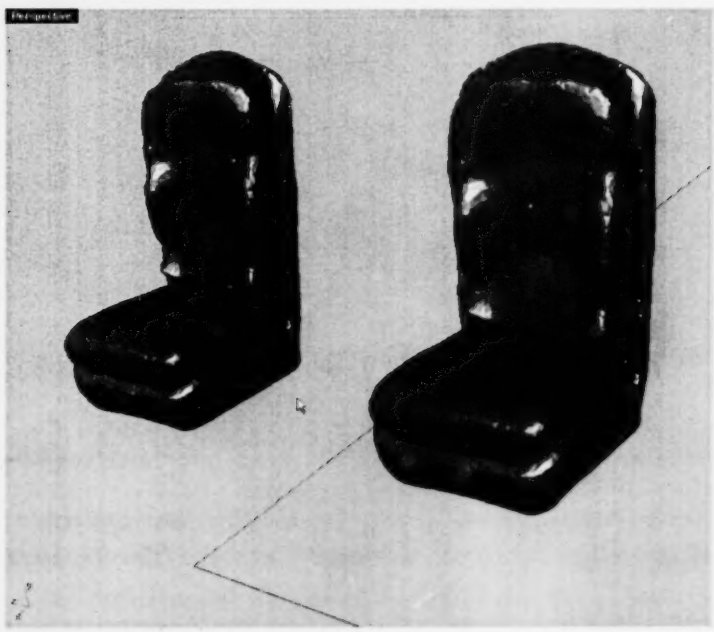

Figure 24. Polygon Seat and Frame Model

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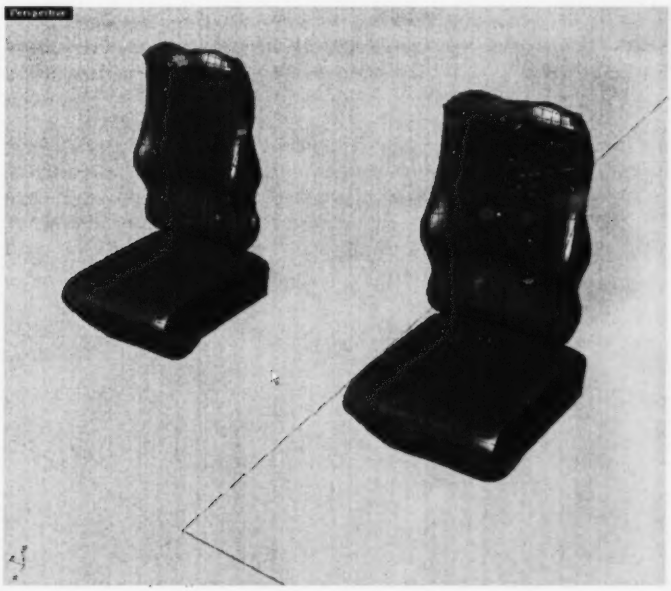

Figure 25. NURBS Seat Cushion Model (Rhino)

2.7.2 Range of Motion on Seat Modelling

[1] The seat range of motions (ROM) are based on the scan data, but the model also applied certain geometrical restrictions for movements. These are:

1. Seats translate forward/back and up/down along their respective seat rails. Note the back rail is not vertical, but is sloped compared to the floor (like the seat back). Thus, up and down translations are tilted with respect to the floor.
2. The seats translate rigidly forward and back on floor mounted rails. Thus, motion is restricted to these axes.
3. Rigid body motion is assumed, as it is with all of the ROM's in this study.
4. Movements are assumed symmetrical for each individual seat, i.e., in both up and down position the horizontal translation is the same, and likewise regardless of the horizontal motion, vertical limits are the same in both extremes, and along the entire ROM. In other words, there are no obstructions along the movement axis, within their limits.
5. No assumption is made that ROM limits are identical for both pilot and co-pilot seats, instead these limits were determined using the scan data.
6. The directions of forward/back and up/down motions of the pilot and co-pilot seats are assumed to be parallel to each other. This assumption is supported by the scan data.

[2] These conditions result in diamond shaped ROM axes, shown in Figure 26 as construction lines and points, along with dimensions shown in meters. Note that the seats are shown in down/back position. These construction lines are stored in Rhino, should further adjustments ever need to be made with new data.

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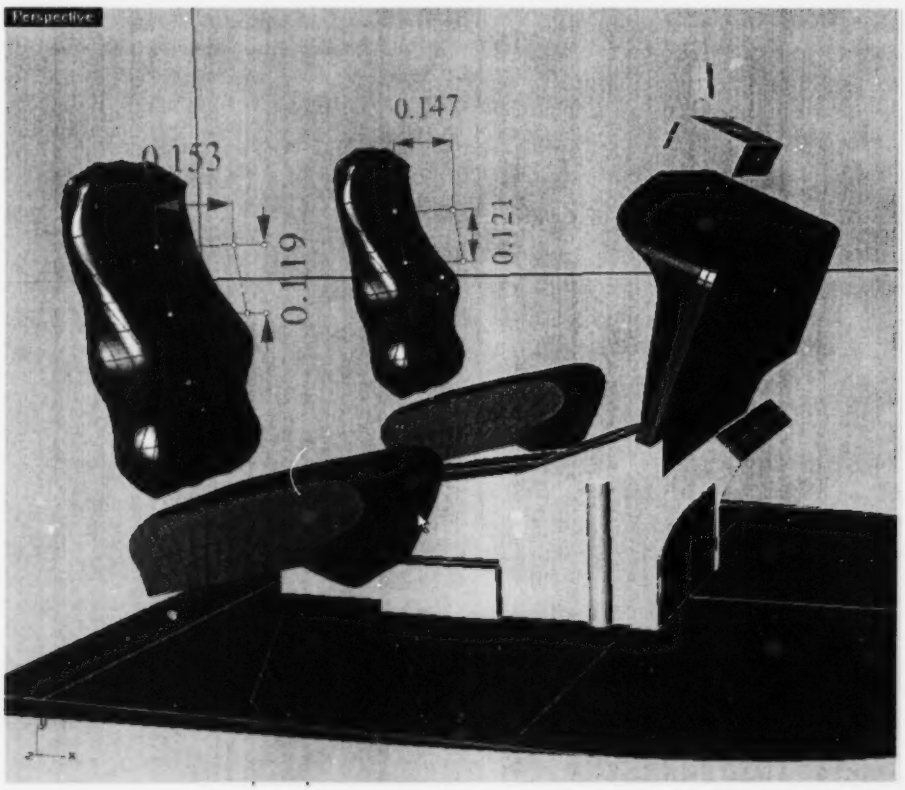

Figure 26. Range of Motion Axis and Positions for Seats

[3] The seat/seat cushion ROM is shown in Figure 27.

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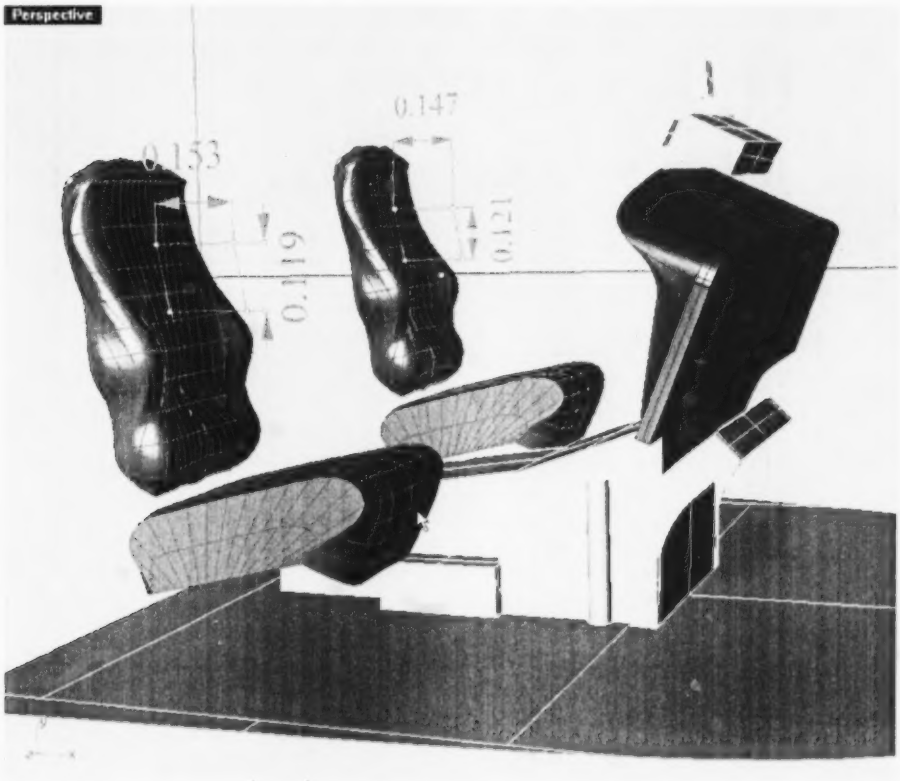

Figure 26. Range of Motion Axis and Positions for Seats

[3] The seat/seat cushion ROM is shown in Figure 27.

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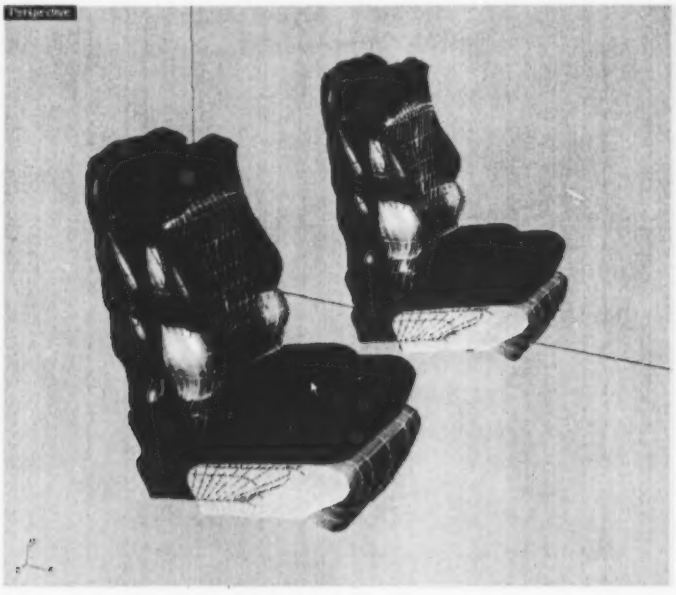

Figure 27. Seat Cushion ROM

[4] From the scans and seat modelling, seat ROM is found to be the following:

Pilot's Seat:	15.3 cm forward/back
	11.9 cm up/down
Co-Pilot's Seat:	14.7 cm forward/back
	12.1 cm up/down

[5] These compare well with tape measured seat ROMS from the second Sea King:

Pilot's Seat:	15.3 cm forward/back
	11.5 cm up/down
Co-Pilot's Seat:	14.7 cm forward/back
	11.5 cm up/down

2.7.3 Cyclic/Seat Collision and Interference Discovery

[1] As mentioned in the notes on the cyclic modelling, there is an apparent collision and interference between the extreme positions of the cyclic and seats. This is shown in Figure 28 and Figure 29. The existence of this physical interference was verified by Robert Mertens, in consultation with Captain Chapman at CFB Halifax. Note that the interference in the model takes place with the seat cushion unloaded and uncompressed (i.e. no one is sitting on it). In actual operational situations, this is unlikely to be the case.

[2] Also note that the extreme cyclic positions are rarely reached in normal flight operations. However, we do recommend that notice be given to CF of this conflict, and appropriate actions be taken. This has taken place as noted above.

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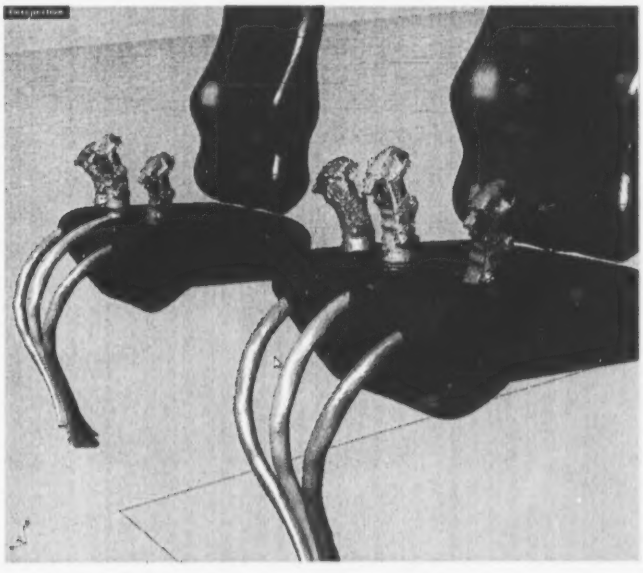

Figure 28. Cyclic/Seat Cushion Collision/Interference

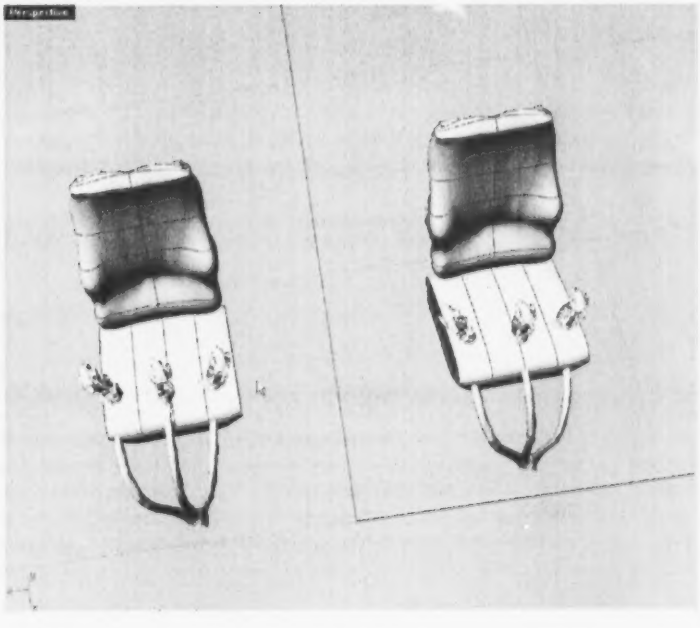

Figure 29. Cyclic/Cushion Collision/Interference

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3 VALIDATION OF MODEL

[1] The final step requested for this call-up was to perform a model validation with respect to the original scan data. For this validation, the final 3D graphics model is compared to the original source scan data used in the modelling using Iminspect. The following is a list of error sources contributing to the errors in the model and modelling:

1. Basic (inherent) scanner sensor noise and repeatability (+/- 6mm one-sigma for Cyra, according to manufactures specifications)
2. Multipath scanner and surface effects (mirroring) – object and site specific (est. +/-2 mm)
3. Uncorrected systematic and random environmental effects (refraction, object and scanner vibration, temperature, pressure, etc.). Especially relevant may be the refraction errors caused by scanning through glass or plexiglass windows. (est +/-5 mm)
4. Model relative component alignment registration and fitting errors and repeatability. (est +/-2 mm)
5. Polygon tolerance reduction effects. (est +/-0.5 mm)
6. Object stability, changes between scans (varies depending on local conditions).
7. Graphics modelling inaccuracies (surface fits, shape deviations, best fitting accuracy). (est +/- 2 mm)
8. Iminspect comparison effect caused by comparison of non-identical objects, and/or noise to 3d graphics model, limited by search distance. (est +/- 3mm)
9. Smoothing/simplification of modelled object shape and size compared to actual shape and size. (Object dependant, est +/- 5 mm)

[2] All of these error sources combine (when added in quadrature) to provide a global error estimate. This can be represented statistically using an RMS error (or std. deviation). The distribution of error can be visualized using Iminspect's colour maps to show the errors magnitudes and directions. For this validation, both indicators are presented below for each sub-group or assembly compared to its originating scan data.

[3] For each subassembly, a statistical summary is shown of the comparison results, along with a sample colour error map. Additional colour error maps, showing different points of view are available in the Iminspect report file, supplied separately. In the statistical table, the mean value represents the accuracy of the objects' position and alignment. The main contributing factor for the mean position will be factors 4 and 8 in the list above. The random error contribution (noise) is primarily represented by the std deviation, also given for each sub-assembly (considered equal to RMS in this case by treating the scan data as the reference data set).

3.1 Front Panel and Consoles

[1] Table 1 and Figure 30 show std deviation of 18.7 mm, and a mean error of 1.3 mm. This indicates the majority of deviations are random error related. Of the 4844 points, 60% are +/- 19mm and 95% are +/- 38 mm. The consoles are subjected to all of the errors noted above. Also, many deviations may be due to the physical dimensions of the instruments affecting the comparison. For this comparison the instrument and dial locations were not considered.

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[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment. One area to note is the lower left part of the console accounting for a significant offset from the scan data. The cause of this error may be systematic and could be investigated further.

Table 1. Front Panels and Consoles

Report Type	Data to Reference (Data Point)
Cmp Object(s)	consoles.pol
Ref	detailed_panel_only_aligned.pol, cyra_scan_panel_aligned.pol
Cmp Dist	0.050000
HiTol +	2.000000
LoTol +	1.000000
LoTol -	-1.000000
HiTol -	-2.000000
Err Dir	Shortest Distance
#Points	4844
Mean	0.001325
StdDev	0.018738
MaxErr +	0.049845
MaxErr -	-0.049913
Max Error	0.049845
Min Error	-0.049913
Pts within +/-(1 * StdDev)	2860 (59.042114%)
Pts within +/-(2 * StdDev)	4768 (98.431049%)
Pts within +/-(3 * StdDev)	4844 (100.000000%)
Pts within +/-(4 * StdDev)	4844 (100.000000%)
Pts within +/-(5 * StdDev)	4844 (100.000000%)
Pts within +/-(6 * StdDev)	4844 (100.000000%)
#Pts Out of HiTol	0 (0.000000%)
#Pts Out of LoTol	0 (0.000000%)

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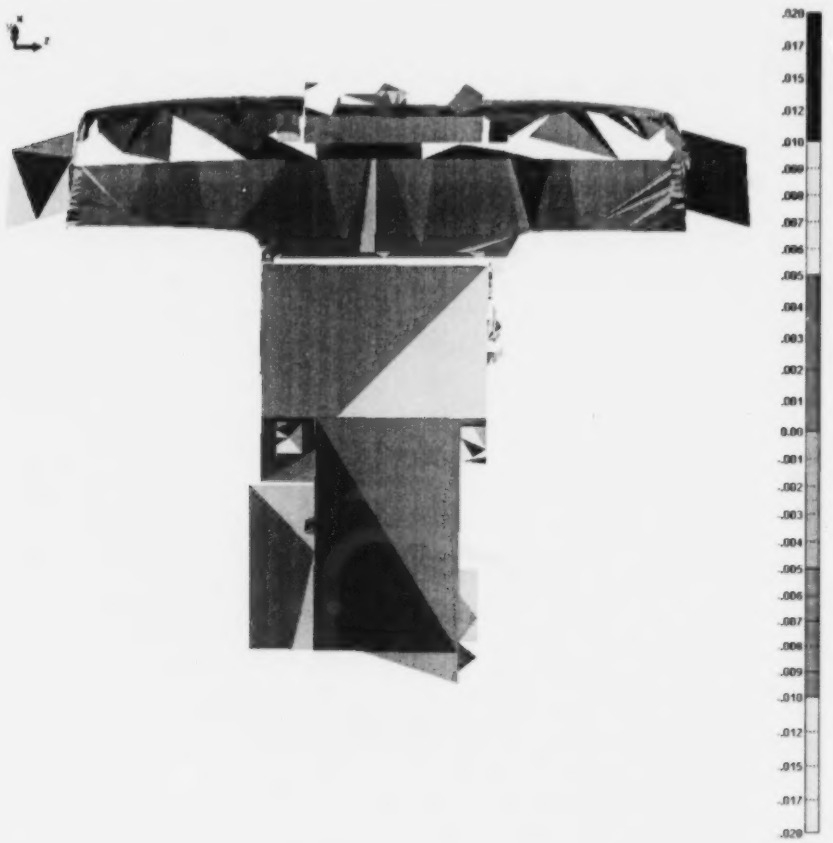

Figure 30. Console Model Error Map

3.2 Collectives

[1] Table 2 and Figure 31 show a std deviation of 19.3 mm, and a mean error of 1.9 mm. This indicates the majority of deviations are random error related. Of the 207485 points, 68% are +/- 19mm and 95% are +/- 38 mm. The collectives are subjected to all of the errors noted above.

[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment.

Table 2. Collectives

Report Type	Data to Reference (Data Point)
Cmp Object(s)	collectives.pol
Ref	left_sticks_aligned.pol, right_sticks_aligned.pol
Cmp Dist	0.050000

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Report Type	Data to Reference (Data Point)
HiTol +	2.000000
LoTol +	1.000000
LoTol -	-1.000000
HiTol -	-2.000000
Err Dir	Shortest Distance
#Points	207485
Mean	0.000193
StdDev	0.019089
MaxErr +	0.049998
MaxErr -	-0.049999
Max Error	0.049998
Min Error	-0.049999
Pts within +/-(1 * StdDev)	141792 (68.338434%)
Pts within +/-(2 * StdDev)	201396 (97.065330%)
Pts within +/-(3 * StdDev)	207485 (100.000000%)
Pts within +/-(4 * StdDev)	207485 (100.000000%)
Pts within +/-(5 * StdDev)	207485 (100.000000%)
Pts within +/-(6 * StdDev)	207485 (100.000000%)
#Pts Out of HiTol	0 (0.000000%)
#Pts Out of LoTol	0 (0.000000%)

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Figure 31. Collective Error Map

3.3 Cyclics

[1] Table 3 and Figure 32 show a std deviation of 21.4 mm, and a mean error of 2.9 mm. This indicates the majority of deviations are random error related. Of the 185048 points, 68% are +/- 22mm and 95% are +/- 44 mm. The cyclics are subjected to all of the errors noted above.

[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment. The pilot and co-pilot cyclic errors are consistent.

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Table 3. Cyclics

Report Type	Data to Reference (Data Point)
Cmp Object(s)	cyclics.pol
Ref	left_sticks_aligned.pol, right_sticks_aligned.pol
Cmp Dist	0.050000
HiTol +	2.000000
LoTol +	1.000000
LoTol -	-1.000000
HiTol -	-2.000000
Err Dir	Shortest Distance
#Points	185048
Mean	0.002888
StdDev	0.021392
MaxErr +	0.049998
MaxErr -	-0.049995
Max Error	0.049998
Min Error	-0.049995
Pts within +/-(1 * StdDev)	126095 (68.141779%)
Pts within +/-(2 * StdDev)	176464 (95.361204%)
Pts within +/-(3 * StdDev)	185048 (100.000000%)
Pts within +/-(4 * StdDev)	185048 (100.000000%)
Pts within +/-(5 * StdDev)	185048 (100.000000%)
Pts within +/-(6 * StdDev)	185048 (100.000000%)
#Pts Out of HiTol	0 (0.000000%)
#Pts Out of LoTol	0 (0.000000%)

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Figure 32. Cyclic Error Map

3.4 Pedals

[1] Table 4 and Figure 33 and Figure 34 show a std deviation of 15.6 mm, and a mean error of –5.8 mm. Of the 77022 points, 68% are +/- 16mm and 95% are +/- 32 mm. The pedals are subjected to all of the errors noted above.

[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment.

Table 4. Pedals

Report Type	Data to Reference (Data Point)
Cmp Object(s)	pedals.pol
Ref	rt_pedal_aft_aligned.pol, rt_pedal_fwd_aligned.pol, left_pedals_aligned.pol

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Report Type	Data to Reference (Data Point)
Cmp Dist	0.050000
HiTol +	2.000000
LoTol +	1.000000
LoTol -	-1.000000
HiTol -	-2.000000
Err Dir	Shortest Distance
#Points	77022
Mean	-0.005824
StdDev	0.015565
MaxErr +	0.049997
MaxErr -	-0.049998
Max Error	0.049997
Min Error	-0.049998
Pts within +/-(1 * StdDev)	58750 (76.276908%)
Pts within +/-(2 * StdDev)	71066 (92.267144%)
Pts within +/-(3 * StdDev)	76100 (98.802939%)
Pts within +/-(4 * StdDev)	77022 (100.000000%)
Pts within +/-(5 * StdDev)	77022 (100.000000%)
Pts within +/-(6 * StdDev)	77022 (100.000000%)
#Pts Out of HiTol	0 (0.000000%)
#Pts Out of LoTol	0 (0.000000%)

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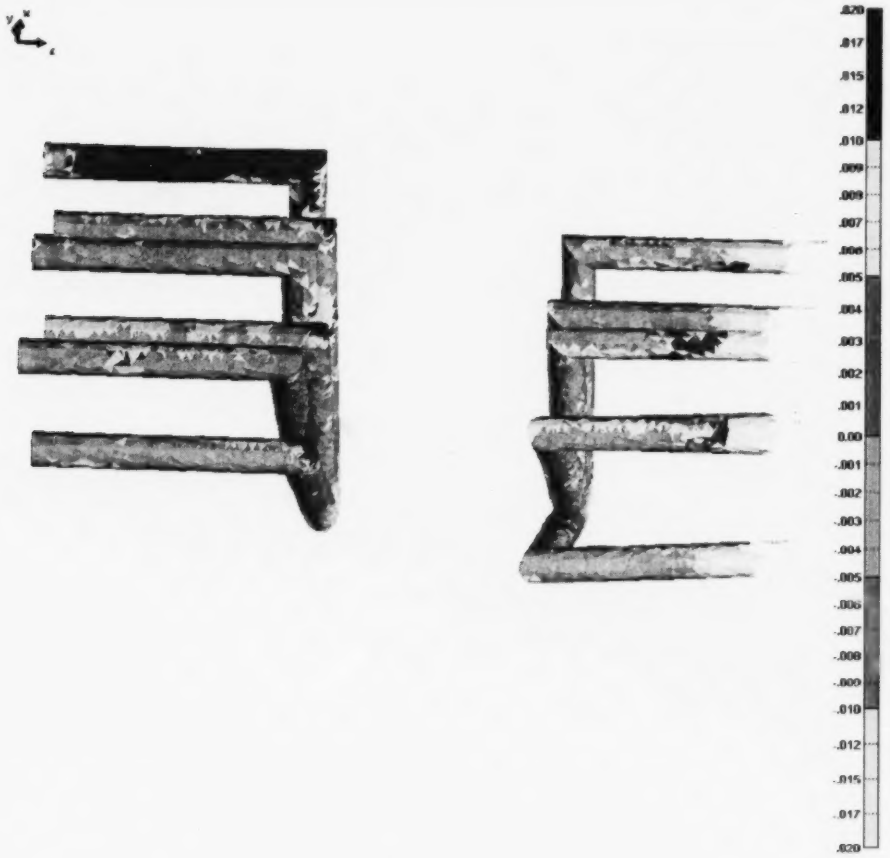

Figure 33. Co-Pilot Pedals Error Map

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Figure 34. Pilot's Pedals Error Maps

3.5 Seats

[1] Table 5 and Figure 35 shows a std deviation of 19.6 mm, and a mean error of –2.7 mm. Of the 18486 points, 68% are +/- 20mm and 95% are +/- 40 mm. The seats are subjected to all of the errors noted above. Note these results are shown for the seat cushions in the down and back position, other positions result in similar values and error distribution.

[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment.

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Table 5. Seats

Report Type	Data to Reference (Data Point)
Cmp Object(s)	seat_cush_down_back_model2.stl
Ref	seat_down_back_aligned.pol
Cmp Dist	0.050000
HiTol +	2.000000
LoTol +	1.000000
LoTol -	-1.000000
HiTol -	-2.000000
Err Dir	Distance Along Y
#Points	18486
Mean	-0.002692
StdDev	0.019563
MaxErr +	0.049974
MaxErr -	-0.049968
Max Error	0.049974
Min Error	-0.049968
Pts within +/-(1 * StdDev)	13143 (71.097046%)
Pts within +/-(2 * StdDev)	17287 (93.514011%)
Pts within +/-(3 * StdDev)	18486 (100.000000%)
Pts within +/-(4 * StdDev)	18486 (100.000000%)
Pts within +/-(5 * StdDev)	18486 (100.000000%)
Pts within +/-(6 * StdDev)	18486 (100.000000%)
#Pts Out of HiTol	0 (0.000000%)
#Pts Out of LoTol	0 (0.000000%)

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Figure 35. Seat Cushion Error Map

3.6 Window Straps and Windows

[1] Table 6 and Figure 36 show a std deviation of 27.4 mm, and a mean error of –3.6 mm. Of the 259657 points, 68% are +/- 27mm and 95% are +/- 54 mm. The shell data is subjected to all of the errors noted above.

[2] The distribution of the errors shown in the colour map appears to be fairly random, indicating a good alignment.

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Table 6. Window Straps and Windows

Report Type	Data to Reference (Data Point)
Cmp Object(s)	front_cockpit_aligned.pol (2)
Ref	ext_shell_new_aligned.pol
Cmp Dist	0.100000
HiTol +	0.050000
LoTol +	0.020000
LoTol -	-0.020000
HiTol -	-0.050000
Err Dir	Shortest Distance
#Points	259657
Mean	-0.003611
StdDev	0.027403
MaxErr +	0.099999
MaxErr -	-0.099996
Max Error	0.099999
Min Error	-0.099996
Pts within +/-(1 * StdDev)	207519 (79.920433%)
Pts within +/-(2 * StdDev)	236831 (91.209172%)
Pts within +/-(3 * StdDev)	252314 (97.172038%)
Pts within +/-(4 * StdDev)	259657 (100.000000%)
Pts within +/-(5 * StdDev)	259657 (100.000000%)
Pts within +/-(6 * StdDev)	259657 (100.000000%)
#Pts Out of HiTol	28671 (11.041874%)
#Pts Out of LoTol	61284 (23.601906%)

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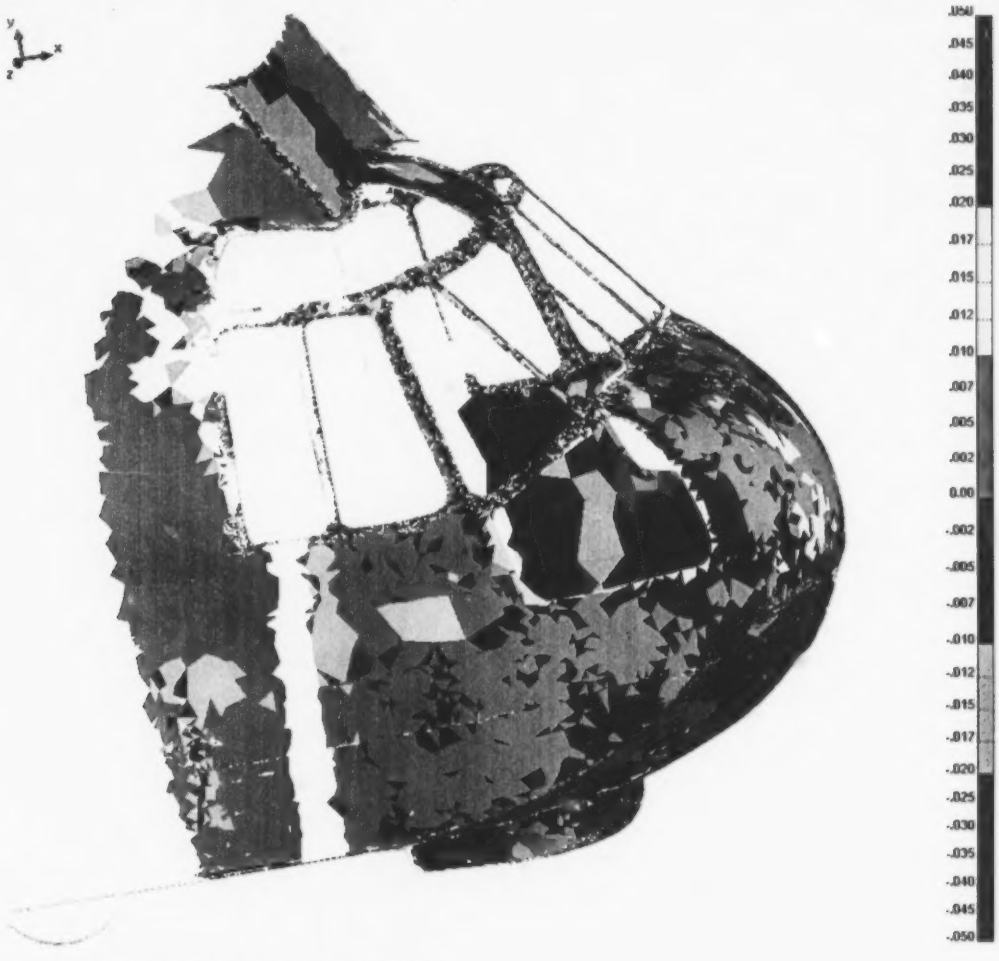

Figure 36. Window and Strap Error Map

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4 DELIVERABLES

[1] This section describes the deliverables presented for this project in addition to this report. The improved 3D graphics model is delivered in three main models – two polygon representations, and one native Rhino model.

4.1 New Sea King Polygon Models

[1] Two new polygon models have been created:

1. new_cockpit_SeaKing.pol
2. new_whole_SeaKing.pol

[2] The models contains polygon representations of the NURBS objects conventionally modelled in Rhino.

[3] The first is a 3D polygon model of the new cockpit, partially shown in Figure 37. The model is structured and layered, with Polygon groups for each range of motion position and subassembly. It is polygon tolerance reduced to 0.5 mm. Individual objects (e.g. cyclic), or positions of objects can be separately exported from this model using Imedit. They (or the whole mode) can also be further tolerance reduced using Imcompress.

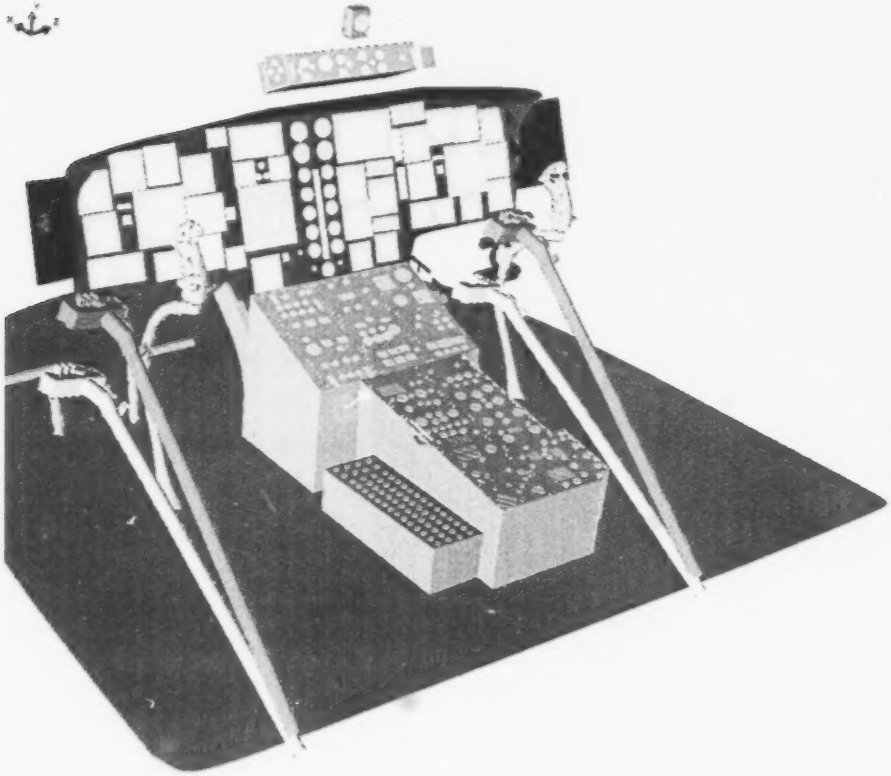

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Figure 37. Part of New Cockpit Model

[4] The second polygon model (shown in Figure 38) includes the above model, and the new interior and exterior shells, windows, and all other previously existing components that were not remodelled. In other words, it consists of the old model with the new objects inserted to replace their previous objects.

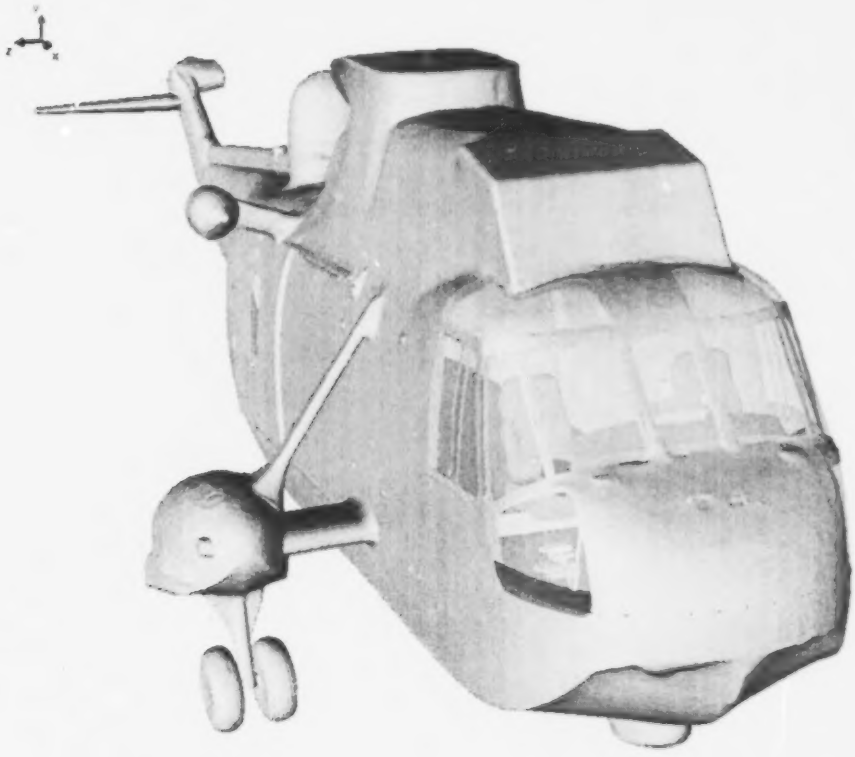

Figure 38. Part of New Sea King Polygon Model

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4.2 New Rhino Model of Cockpit Interior

[1] In addition to the Polygon models listed above, the Rhino V3.0 format file new_cockpit_SeaKing.3dm, illustrated in Figure 39, contains the NURBS objects for the new model.

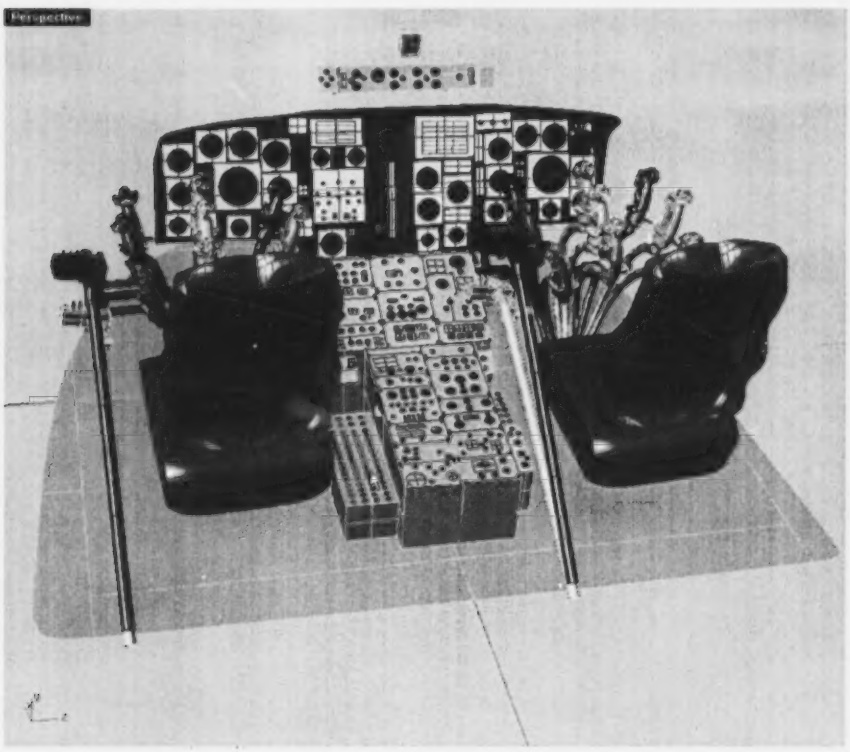

Figure 39. New Rhino Model of Cockpit

[2] Like the polygon model, the Rhino model also is layered and structured by objects. As described previously, except for the cyclics, all objects are conventionally surfaced NURBS objects. From Rhino, objects, or groups of objects may be selected and exported to numerous formats including dxf, stl, obj, etc.

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14. ABSTRACT

(U) An improved 3D graphics model of the interior and exterior of a SeaKing Helicopter has been developed for simulation and modelling purposes. An existing polygon graphics model was modified to include some missing features, improve certain features, and to add range of motion objects for pedals, sticks, and seats. The interior model was surfaced conventionally using NURBS objects to improve storage and operating efficiency. The polygon model was created using Innovmetric Polyworks software and the NURBS using the Rhino modelling package. Models were built from laser scan data measured by Cyrax and Shape Grabber laser scanners, and consist of polygon and/or NURBS surfaces of the interior and exterior of the SeaKing. They incorporate range of motion objects for the seats, pedals, control sticks. They also include schematic representations of the position of major panel and console dials, indicators and controls. A validation of the final models compared to the original scan data indicates a mean error of less than 3 mm.

(U) Un modèle graphique 3D amélioré de l'intérieur et de l'extérieur d'un hélicoptère Sea King a été élaboré pour répondre aux besoins en simulation et en modélisation. Un modèle graphique en polygones existant a été modifié afin d'inclure quelques caractéristiques manquantes, d'améliorer certaines caractéristiques et d'ajouter la plage de déplacement des objets pour les pédales, les manches et les sièges. On a surfacé le modèle de l'intérieur de manière classique par la technique des objets NURBS afin d'améliorer le stockage et l'efficacité opérationnelle. Le modèle en polygones a été créé au moyen du logiciel Innovmetric Polyworks et de la technique des objets NURBS à l'aide du groupe de modélisation Rhino. Les modèles ont été construits à partir de données de balayage au laser obtenes à l'aide de scanners au laser Cyrax et Shape Grabber, et ils sont constitués de polygones et (ou) de surfaces NURBS de l'intérieur et de l'extérieur d'un Sea King. Les modèles comprennent la plage de déplacement des objets pour les sièges, les pédales et les manches de commande. Ils comprennent également des représentations schématiques de la position des principaux cadrans de panneaux et de pylônes de commande, des indicateurs et des commandes. Une validation des modèles finaux par rapport aux données de balayage originales indique une erreur moyenne inférieure à 3 mm.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) 3D laser scanning, 3D modelling, Sea King